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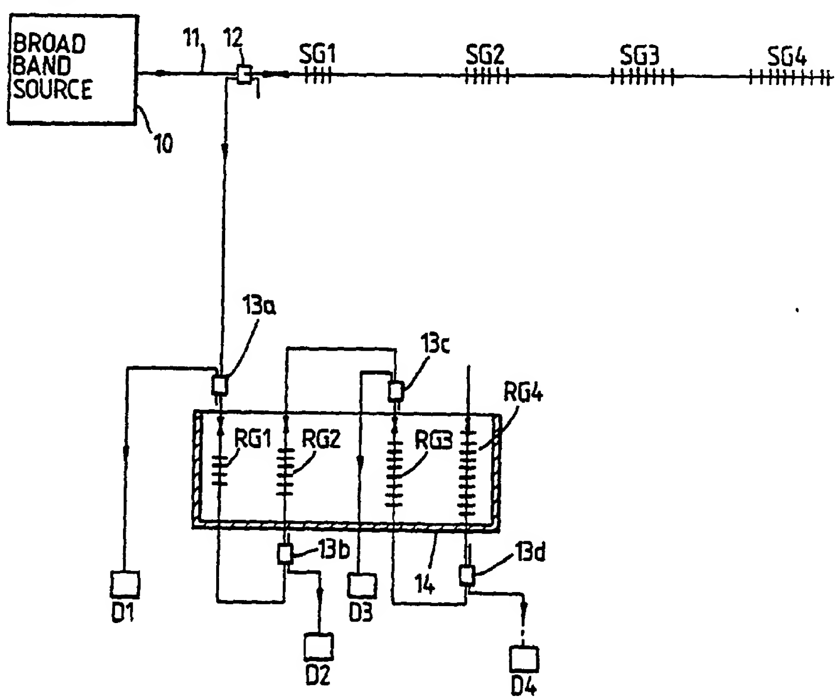
(54) Optical fibre diffraction grating sensor

(57) Fibre diffraction gratings SG1-SG4 working in different bands reflect narrow bands of the incident broadband radiation 10. The reflected light wavelength depends on the grating pitch, allowing strain or temperature to be detected. The pitch of receiver gratings RG1-RG4 is modulated by e.g. a PZT device so that pulses are detected by photodiodes D1-D4 when the respective grating pitches match. Time of occurrence of the detected pulses with respect to the modulation conveys the sensed parameters. Multiple fibres may be accommodated by pulsing the source and using fibre delay lines.

Fig.2.



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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Fig.1.

1/2

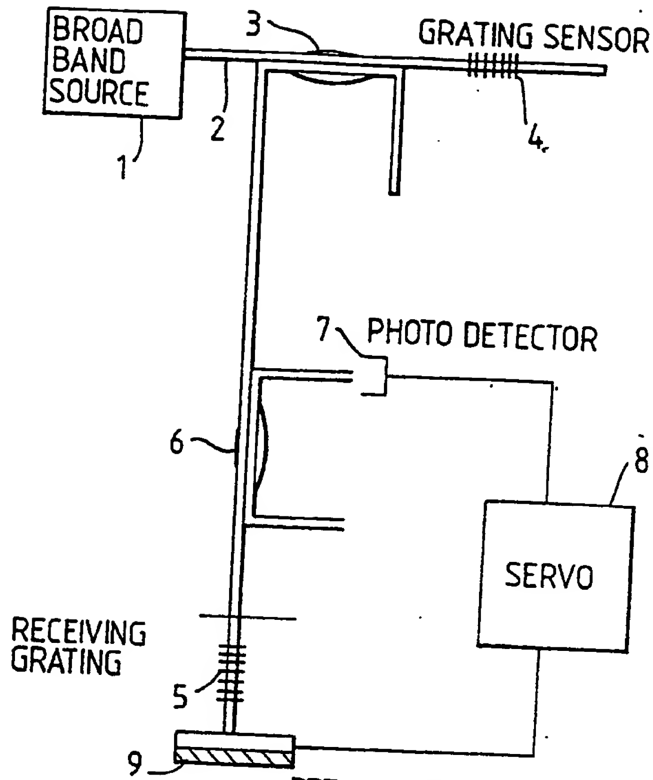

BROAD BAND SOURCE
GRATING SENSOR
PHOTO DETECTOR
SERVO
RECEIVING GRATING
PZT ELEMENT
1
2
3
4
5
6
7
8
9

Fig.2.

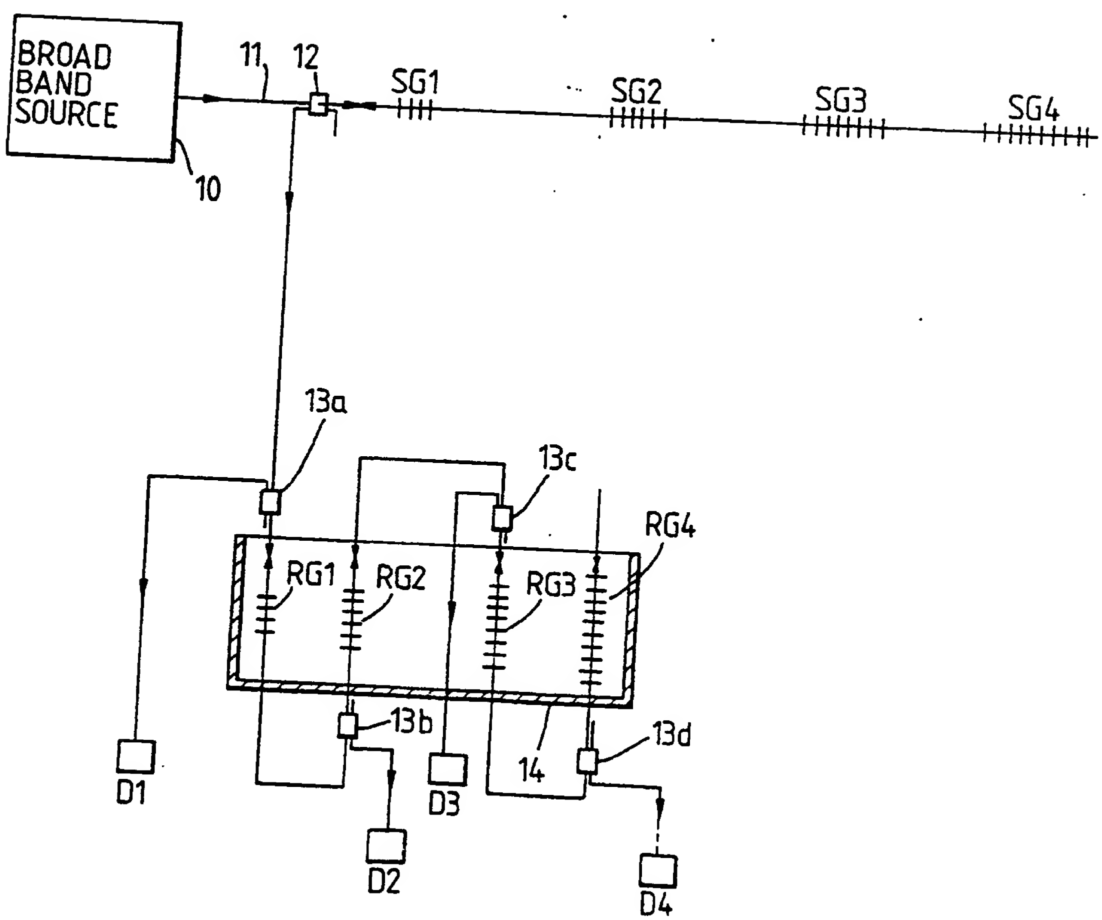
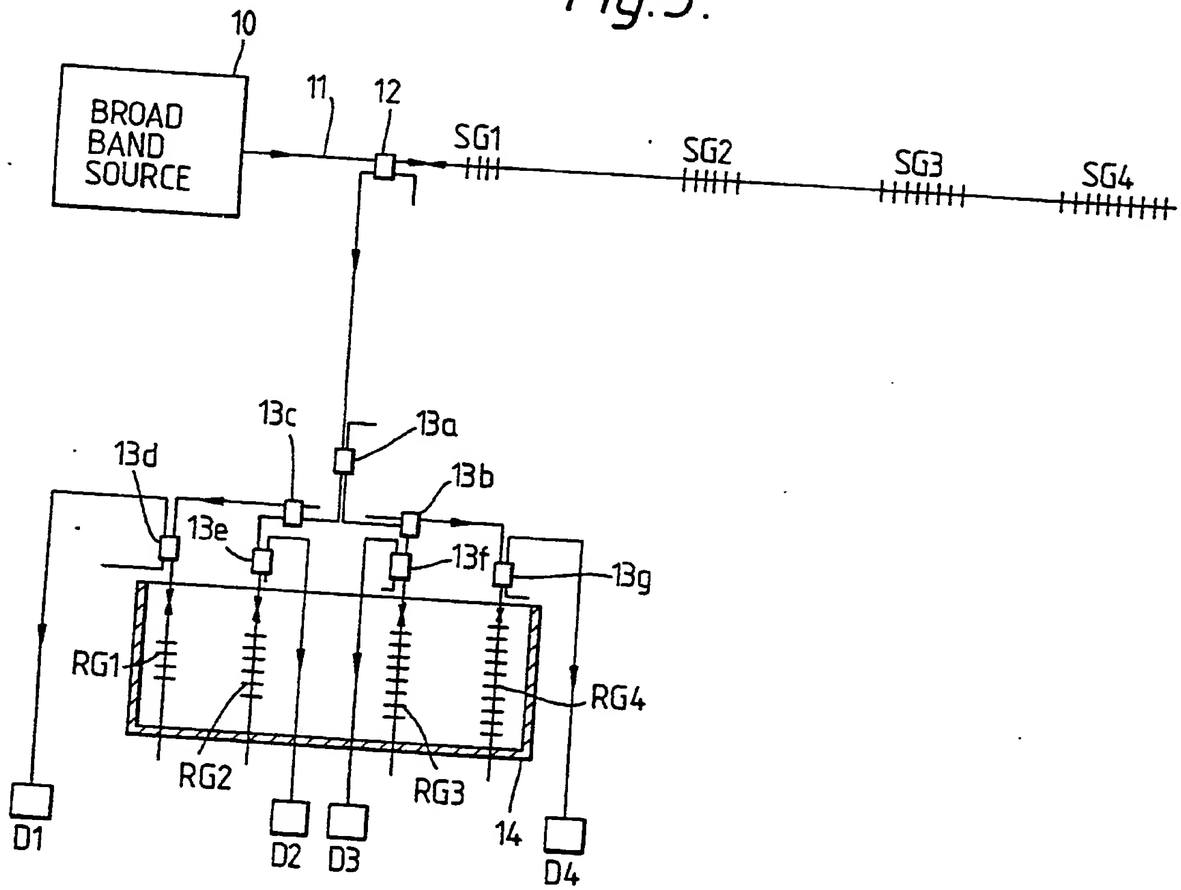

BROAD BAND SOURCE
10
11
12
SG1
SG2
SG3
SG4
13a
13b
13c
13d
RG1
RG2
RG3
RG4
14
D1
D2
D3
D4

Fig.3.


10
BROAD
BAND
SOURCE
11
12
SG1
SG2
SG3
SG4
13c
13a
13d
13b
13e
13f
13g
RG1
RG4
RG2
RG3
14
D1
D2
D3
D4

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Apparatus for Establishing Matching Conditions
Between Two Optical Fibre Gratings

The invention relates to an apparatus for establishing matching conditions between two optical fibre gratings such that a maximum reflectivity to light provided by one of said gratings becomes equal to that provided by other of said gratings.

According to the invention there is provided an apparatus for establishing matching conditions between two optical fibre gratings such that a maximum reflectivity to light provided by one of said gratings becomes equal to that provided by other of said gratings, the apparatus comprising an optical light source with a bandwidth of $\lambda_1 - \lambda_2$ an optical fibre provided with a first reflection grating, an optical coupler for coupling light of bandwidth $\lambda_1 - \lambda_2$ from said source into said fibre, the first grating being capable of reflecting light propagated thereto along said fibre with a maximum reflectivity in a narrow band with a centre frequency between $\lambda_1 - \lambda_2$, means for transferring along an optical fibre the reflected light from the first grating to a second reflection grating provided in the optical fibre, means for detecting the light reflected from the second grating, and means for adjusting the pitch of the second grating such that the second grating provides a maximum reflectivity.

Preferably the detecting means includes a photodiode and the adjusting means includes a piezo electric element on which said second grating is mounted. The pitch of the second grating is adjusted by applying a voltage drive signal to the piezo electric element.

The wavelength at which a fibre grating provides a maximum reflectivity and its bandwidth depends on pitch of the fibre grating. If the grating is subjected to either a temperature change or an elongated force (stress), then the wavelength at which the maximum reflectivity occurs will change.

In one embodiment of the invention the first grating is arranged at a location remote from said second grating to sense temperature changes and/or stress at the remote location. The pitch of the first grating is changed on subjecting said first grating to temperature changes and/or stress at said location whereby the wavelength at which the maximum reflectivity occurs at said first grating is changed. The pitch of the second grating is changed by said adjusting means so that it becomes equal to the pitch of the first grating thereby providing a maximum reflectivity by said second grating, the voltage drive signal applied to the adjusting means to maximise the reflectivity of the second grating being proportional to the temperature changes and/or stress to which said first grating is subjected. Prior to subjecting the first grating to temperature changes and/or stress, the pitch of the first and second gratings may be calibrated. Preferably the pitch of the second grating is adjusted to be equal to the pitch of the first grating, prior to subjecting the first grating to a temperature change and/or stress.

Preferably a feedback servo is connected between said detecting means and said adjusting means. The servo is operable to apply a voltage drive signal to the adjusting means to maximise the reflectivity of the second grating.

Further, according to the invention there is provided an apparatus for establishing matching conditions between optical fibre gratings of each pair of a plurality of pairs of optical fibre gratings such that a maximum reflectivity to light provided by a first

grating of each of said pairs of gratings becomes equal to that provided by its associated second grating, the apparatus comprising an optical light source with a bandwidth of $\lambda_1 - \lambda_m$, an optical fibre provided with a plurality of first reflection gratings arranged in series, an optical coupler for coupling light of bandwidth $\lambda_1 - \lambda_m$ from said source into said fibre, each of the first gratings being capable of reflecting light propagated thereto along said fibre with a maximum reflectivity in a narrow band with centre frequency lying in its associated wavelength range ($\lambda_1 - \lambda_2$, $\lambda_2 - \lambda_3$ ---- $\lambda_{m-1} - \lambda_m$), means for transferring along the optical fibre the reflected light from the first gratings to a plurality of second reflection gratings provided in the optical fibre, means for detecting the light reflected from the second gratings, and means for adjusting the pitch of the second gratings such that when the pitch of a second grating becomes equal to the pitch of its associated first grating a maximum reflectivity is detected by said detecting means.

Preferably the second gratings are connected in a series format.

Preferably the adjusting means includes a piezoelectric element on which said second gratings are mounted. The pitch of the second gratings are adjusted by applying a voltage drive signal to the piezoelectric element.

In another embodiment the second gratings are connected in a parallel format and the adjusting means includes a plurality of piezoelectric elements, on each of which a second grating is mounted. The pitch of each of the second gratings is adjusted by applying a voltage drive signal to its associated piezoelectric element.

In an embodiment in which a plurality of pairs of first and second gratings are provided, the first gratings are arranged at locations remote from said second gratings to sense temperature changes and/or stress at said remote locations, the pitch of each of the first gratings being changed on subjecting it to temperature changes and/or stress at its location. The pitch of each of the second gratings is changed by said adjusting means so that it becomes

equal to the pitch of its associated first grating thereby providing a maximum reflectivity by the second grating. The voltage drive signal applied to the adjusting means to maximise the reflectivity of the second grating is proportional to the temperature changes and/or stress to which the first grating is subjected. Prior to subjecting the first gratings to temperature changes and/or stress, each pair of gratings is preferably calibrated.

The invention will now be described further by way of example with reference to the accompanying drawings in which:

Figure 1 illustrates a remote fibre grating sensor for sensing a temperature change and/or stress at a remote location;

Figure 2 illustrates another embodiment of the invention including a plurality of fibre grating sensors for sensing temperature changes and/or stress at a plurality of remote location; and

Figure 3 illustrates still another embodiment of the invention including a plurality of fibre grating sensors.

Referring to Figure 1, light from a broad band optical source 1 with a bandwidth $\lambda_1 - \lambda_2$ is coupled into an optical fibre 2 via a directional coupler 3 and is propagated towards a sensing grating 4 formed in the optical fibre. Light with a very narrow bandwidth with a centre frequency between $\lambda_1 - \lambda_2$ is reflected back from the sensing grating 4. This light is transferred to a receiving grating 5 via a coupler 6. Light reflected from the receiving grating 5 is detected by a photodetector 7 which is a photodiode. In general the wavelength of maximum reflectivity for the receiving grating 5 will not match that of the sensing grating 4. If the pitch of receiving grating 5 is varied a 'matching condition' would be established when the pitch of both the sensing grating and the receiving grating are equal. For this condition a maximum signal will be detected at the photo-detecotor 7. In order to maintain this condition a combination of a feedback servo 8 and a piezoelectric element 9 are used. If the servo 8 operates to continuously maximise the signal, a voltage drive signal applied to the piezoelectric element would be directly proportional to the pitch of the receiving grating 5 which would be

identical to the pitch of the sensing grating 4. Thus the instantaneous strain or change in temperature at the location of the sensing grating 4 can be determined.

The arrangement for multiplexing grating sensors deployed in a series format with in series signal recovery is shown in figure 2. Each sensing grating SG has a working wavelength range of centred at difference wavelengths, ie. SG1 operates from $\lambda_1 - \lambda_2$ SG2 from $\lambda_2 - \lambda_3$ and so on. Light from a broadband source 10 is coupled into a fibre 11 via a directional coupler 12 and is propagated towards the sensing gratings SG1, SG2,SG3, SG4 -----. For a plurality of sensing gratings (m) the bandwidth of broadband light source 10 is greater than Light is reflected back from the sensing gratings SG at discrete wavelengths in the range $(\lambda_1 - \lambda_2)$, $(\lambda_2 - \lambda_3)$...$(\lambda_m - \lambda_{m+1})$ where the current wavelength of maximum reflectivity of each sensing grating is SG1 , SG2 , SG3 ,SG4 ------. This light is coupled via directional couplers 13a-13d into a serial demodulation network as shown in Figure 2, where the working ranges of the receiving gratings RG1, RG2, RG3, RG4 correspond to $(\lambda_1 - \lambda_2)$, $(\lambda_2 - \lambda_3)$..$(\lambda_m - \lambda_{m+1})$. Light reflected from the set of receiving gratings, deployed in series is detected by photo detectors D, where D1 detects the signal from RG1. D2 from RG2, D3 from RG3 and D4 from RG4.

When the pitch of receiving grating RG1 becomes equal to the pitch of the sensing grating SG1, the signal detected at D1 would be a maximum; signals at D2, D3, and D4 would also be at maximum when the pitch of their associated pairs of gratings become equal. Hence the pitch of the sensing gratings SG can be determined if the pitch of the receiving gratings RG are tuned to the pitch of the sensing gratings. This can be accomplished in several ways; one possible method is indicated in Figure 2. Here all the receiving gratings are mounted on a single piezoelectric element 14, typically a cylinder, such that all the receiving gratings can be simultaneously stretched by applying a voltage to the piezoelectric element 14. When a specific sensing - receiving grating pair is matched the output of the corresponding photodiode would be at a maximum. The pitch of the sensing grating

can be determined from a voltage drive signal applied to the piezoelectric element when the photodiode output is a maximum. The piezoelectric element can be driven linearly or sinusoidally. The output from each photodiode, when its corresponding sensing receiving grating pair are matched, would be a sharp pulse. Sinusoidal modulation is likely to be preferred even though the dwell times per voltage increment are not linear, as the processing rate will be the fastest (particularly if the PZT is driven at resonance). The normal hysteresis and ringing effects, which occur when the piezoelectric element is linearly driven, are also avoided. For optimum performance the optical power received by each sensor should be equal, this can be accomplished if the coupling efficiences of the fibre couplers associated with the receiving gratings are weighted appropriately.

Figure 3 illustrates another embodiment of a sensor which is similar to that shown in Figure 2 except that the receiving gratings RG are arranged in a parallel format and the power coupled into each RG is identical, hence the system may be simpler to manufacture. The method of processing is identical. In principal each RG could be mounted on a separate piezoelectric element and driven in a closed loop mode as shown in Figure 1.

Another major advantage of the configuration shown in Figure 3 is that the "cross-talk" between sensors is minimized such that it may be preferred to the embodiment shown in Figure 2. Alternative configurations not shown should include a plurality of sensing fibre elements, SE1.... SEN containing a single grating sensor, or a number of grating sensors implemented along the fibre in a similar manner to that shown in Figures 2 and 3. In the case when only 1 sensing grating is implemented per fibre the demultiplexing arrangements shown in Figures 2 or 3 are used. In the case where there are a plurality of grating sensors implemented on each of the fibre sensing elements then fibre delay lines are incorporated into the elements SE1 .... SEN. The optical source is now pulsed and the delays adjusted such that the set of returning pulses from SE1 ... SEN

do not overlap in time. The signals are then recovered using the PZT arrangement shown in Figure 3 where the outputs of the Detectors are gated and the sequential signals from SE1 .... SEN are separated. This arrangement allows the total number of sensors that may be interrogated to be extended, i.e. if ten gratings were implemented on each sensing fibre element and the number of sensing fibre elements were 10 then a 100 separate sensors could be interrogated by this technique.

CLAIMS

1. An apparatus for establishing matching conditions between two optical fibre gratings such that a maximum reflectivity to light provided by one of said gratings becomes equal to that provided by other of said gratings, the apparatus comprising an optical light source with a bandwidth of $\lambda_1 - \lambda_2$, an optical fibre provided with a first reflection grating, an optical coupler for coupling light of bandwidth $\lambda_1 - \lambda_2$ from said source into said fibre, the first grating being capable of reflecting light propagated thereto along said fibre with a maximum reflectivity in a narrow band with a centre frequency between $\lambda_1 - \lambda_2$, means for transfering along an optical fibre the reflected light from the first grating to a second reflection grating provided in the optical fibre, means for detecting the light reflected from the second grating, and means for adjusting the pitch of the second grating such that the second grating provides a maximum reflectivity.

2. An apparatus according to Claim 1, wherein said detecting means includes a photodiode.

3. An apparatus according to Claim 1 or 2, wherein said adjusting means includes a piezoelectric element on which said second grating is mounted, the pitch of the second grating being adjusted by applying a voltage drive signal to the piezo electric element.

4. An apparatus according to Claim 3, wherein said first grating is arranged at a location remote from said second grating to sense temperature changes and/or stress at said remote location, the pitch of the first grating being changed.on subjecting said first grating to temperature changes and/or stress at said location whereby the wavelength at which the maximum reflectivity occurs at said first grating is changed, the pitch of the second grating being changed by said adjusting means so that it becomes equal to the pitch of the first grating thereby providing a maximum reflectivity by said second

grating, the voltage drive signal applied to the adjusting means to maximise the reflectivity of the second grating being proportional to the temperature changes and/or stress to which said first grating is subjected.

5. An apparatus according to Claim 1 including a feedback servo connected between said detecting means and said adjusting means, the servo being operable to apply a voltage drive signal to the adjusting means to maximise the reflectivity of the second grating.

6. An apparatus for establishing matching conditions between optical fibre gratings of each pair of a plurality of pairs of optical fibre gratings such that a maximum reflectivity to light provided by a first grating of each of said pairs of gratings becomes equal to that provided by its associated second grating, the apparatus comprising an optical light source with a bandwidth of $\Lambda_1 - \Lambda_m$, an optical fibre provided with a plurality of first reflection gratings arranged in series, an optical coupler for coupling light of bandwidth $\Lambda_1 - \Lambda_m$ from said source into said fibre, each of the first gratings being capable of reflecting light propagated thereto along said fibre with a maximum reflectivity in a narrow band with centre frequency lying in its associated wavelength range $(\Lambda_1 - \Lambda_2, \Lambda_2 - \Lambda_3 \cdots \Lambda_{m-1} - \Lambda_m)$, means for transferring along the optical fibre the reflected light from the first gratings to a plurality of second reflection gratings provided in the optical fibre, means for detecting the light reflected from the second gratings, and means for adjusting the pitch of the second gratings such that when the pitch of a second grating becomes equal to the pitch of its associated first grating, a maximum reflectivity is detected by said detecting means.

7. An apparatus asccording to Claim 6, wherein said detecting means includes a plurality of photodiodes, each being arranged to detect light from its associated second grating.

8. An apparatus according to Claim 6 or 7, wherein said second gratings are arranged in a series format.

9. An apparatus according to Claim 6 or 7, wherein said second gratings are arranged in a parallel format.

10. An apparatus according to anyone of Claims 6 to 9, wherein said adjusting means includes a piezoelectric element on which said second gratings are mounted, the pitch of said second gratings being adjusted by applying a voltage drive signal to the piezoelectric element.

11. An apparatus according to Claim 9, wherein said adjusting means includes a plurality of piezoelectric elements, on each of which a second grating is mounted, the pitch of each of the second gratings being adjusted by applying a voltage drive signal to its associated piezoelectric element.

12. An apparatus according to Claim 6, wherein said first gratings are arranged at locations remote from said second gratings to sense temperature changes and/or stress at said remote locations, the pitch of each of the first gratings being changed on subjecting it to temperature changes and/or stress at its location, the pitch of each of the second gratings being changed by said adjusting means so that it becomes equal to the pitch of its associated first grating thereby providing a maximum reflectivity by the second grating, the voltage drive signal applied to the adjusting means to maximise the reflectivity of the second grating being proportional to the temperature changes and/or stress to which the first grating is subjected.

13. An apparatus for establishing matching conditions between two optical fibre gratings substantially as hereinbefore described with reference to Figures 1, 2 or 3 of the accompanying drawings.

14. An optical fibre grating sensor for sensing temperature changes and/or stress at one or more locations substantially as hereinbefore described with reference to Figures 1, 2 or 3 of the accompanying drawings.

Patents Act 1977
Examiner's r p rt to th C mptroller under Section 17 (Th S arch Rep rt)

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R l vant Technical fields

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(ii) Int Cl (Edition 5) G01B, G01N

Search Examiner

K SYLVAN

Databases (see over)

(i) UK Patent Office

(ii)

ONLINE DATABASES: WPI

Date of Search

4 SEPTEMBER 1992

Documents considered relevant following a search in respect of claims 1-14

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
	NONE	

SF2(p)

TP - doc99\fil000313

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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